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The Incremental Constriction Model for the Description of Vowel Height*

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1 Introduction

This paper explores the description of vowel height, arguing for a new model for its representation. The current proposal, the incremental constriction model, describes vowel height with multiple occurrences of the feature [closed]. This model is used to analyze height harmony in a number of languages, from which a previously undocumented generalization emerges; all cases of partial height harmony involve one-step raising. The discussion in this paper demonstrates that this generalization is true for all known cases of partial height harmony, and further, that this generalization is uniquely captured by the incremental constriction model.

The description of vowel height has posed a problem for generative phonology since Chomsky and Halle (1968) proposed the binary features [high] and [low] for the characterization of vowel height contrasts. While these features are widely used to describe vowel height, there have been numerous proposals to the contrary. In the year following the publication of *The Sound Pattern of English* (Chomsky and Halle 1968), Contreras (1969) argued that [high] and [low] should be replaced by a multivalued height feature in order to properly account for a hypothetical language in which all non-high vowels raise a single step. Contreras was the first of many authors to express dissatisfaction with the features [high] and [low]. Some authors have sought to modify [high] and [low] by positing these features to be monovalent (e.g., Selkirk 1991, Dyck 1995), while others have argued, as did Contreras, that [high] and [low] be abandoned altogether and replaced by multivalued features (e.g., Lindau 1975), or by scalar[1] features (Schane 1984, 1990, Clements 1989, 1991), still others have argued for a distinct set of unrelated features (e.g., Goad 1993).

Thus, Chomsky and Halle's (1968) proposal has never enjoyed a non-controversial status. A cross-linguistic examination of partial height harmony reveals that many of the

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[1] Multivalued and scalar approaches differ in that the former employs a single feature that has multiple values so that one vowel is [1high] and another [3high], while the latter uses more than one instance of the same feature.

proposals mentioned above cannot account for the robustly attested phenomenon of one-step raising in which vowels of several heights raise one degree. In addition, all of these proposals miss important generalizations concerning partial height harmony. This paper will demonstrate that all cases of partial height harmony involve a *one-step* change in height, and that all such harmonies *raise* their target vowels. Only the incremental constriction model, proposed here, captures these generalizations.

2 The Incremental Constriction Model

In this section, the incremental constriction model is introduced, the properties of this model are discussed, predictions of this model are delineated, and the incremental constriction model is implemented to account for partial height harmony in Llogoori. The analysis of Llogoori, and all other languages discussed in this paper, is framed within the constraint-based approach of optimality theory (Prince and Smolensky 1993). Within optimality theory, assimilation is generally accounted for by the ranking of 'alignment' constraints (Kirchner 1993, Pulleyblank 1993 and others). The alignment constraints required to handle the wide range of languages that exhibit partial height harmony are quite similar cross-linguistically, varying only with respect to three parameters. The form of alignment constraints involved in partial height harmony is discussed in this section.

2.1 The model

In the incremental constriction model, vowel height distinctions are treated as steps along a single phonetic scale, characterized by occurrences of the feature [closed] so that eahc heigh in a language corresponds to an additional instance of [closed]. In this model, the lowest vowels of any language are specified for no occurrences of [closed], but all non-low vowels are specified for at least one instance of [closed] and each higher vowel has an additional occurrence of this feature.

(1) The Incremental Constriction Model.

Height
|
[closed]
|
[closed]
|
[closed]

In a language containing three vowel heights, two occurrences of [closed] are required to characterize the inventory. In such a language (2), the lowest vowels are specified for no occurrences of [closed], the mid vowels are specified for a single occurrence of [closed], and the high vowels are specified for the maximum number of occurrences of [closed] active in the language, in this case, two instances of [closed].

(2) Three vowel heights.

	high	mid	low
[closed]	•	•	
[closed]	•		

(3) Four vowel heights.

	high	mid-hi	mid-lo	low
[closed]	•	•	•	
[closed]	•	•		
[closed]	•			

In a language containing four vowel heights, three occurrences of [closed] are required to characterize the inventory. In such a language (3), the low vowel is specified for no occurrences of [closed], the next lowest vowels are specified for one occurrence of [closed], the next lowest are specified for two occurrences of [closed], and the highest vowels are specified for the maximum number of occurrences of [closed] active in the

language, three. Thus, the number of occurrences of [closed] that are active in a language is determined by the number of heights in that language.

Occurrences of [closed] correspond to increased constriction in the vocal tract, and thereby increasing vowel height. The feature [closed] raises a vowel when this feature is inserted, spread, etc. The feature [closed] is defined in terms of first formant frequency (F_1), the acoustic property most reliably correlated to vowel height (Ladefoged 1971, Lindau 1975, Tranmüller 1981, inter alia). The relationship between F_1 and vowel height are inversely related so that low vowels have a relatively higher F_1 while high vowels have a lower F_1. The feature [closed], therefore, is defined in terms of decreased F_1.

The feature [closed] is *incremental* since multiple occurrences of this feature may characterize a single vowel. Characterizing vowel height with incremental features allows vowel height to be treated as a single phonetic scale. Other authors have suggested that vowel height be characterized with multiple occurrences of a single feature (Clements 1991, Schane 1984, 1990), though these models differ from the incremental constriction model where vowel height is exclusively characterized in terms of a feature that corresponds to increased height.

The feature [closed] is monovalent so that languages may only insert, spread, or delink the presence of this feature. In contrast, binary models posit that each feature in the system has two values; positive [+] and negative [–], such that both values are expected to spread, delink, etc. cross-linguistically. It has been argued that reference to both values of a feature is unnecessary, and that where possible, only one value of a feature is recognized. Monovalent features have been argued for with respect to many features. The feature [labial], for example, is widely accepted as monovalent since the phonology of no language makes reference to the negative value, [–labial] (Selkirk 1993). Characterizing vowel height contrasts in terms of monovalent elements has been argued for by many authors, including Schane (1984 1990), Anderson and Ewen (1987), Kaye et. al. (1985), Selkirk (1991), and Goad (1993).

2.2 Predictions of the incremental constriction model

In the incremental constriction model (1), all occurrences of [closed] are organized into a single constituent, Height,[2] in recognition of the fact that many languages refer to this set of features as a group (Odden 1991, Clements 1991, Wiswall 1991, Goad 1993, Parkinson 1994). Such an organization correctly predicts that languages may exhibit assimilations in which one vowel assimilates to another for height such that both vowels surface with identical heights (Odden 1991, Clements 1991). An assimilation of this type is called a *complete height harmony* (Parkinson 1994) and is expressed as the simultaneous assimilation for all height features (Clements 1991, Odden 1991, Wiswall 1991, Goad 1993). Complete height harmony is discussed and contrasted with partial height harmony in §4.

Some height assimilations are not complete, rather a vowel may move toward the height of another vowel, but not attain the height of that vowel. Such an assimilation is called a *partial height harmony* (Parkinson 1994). In partial height harmony, a vowel surfaces with a height between its own (original) height and that of a trigger. It is argued here that partial height harmony is expressed as an assimilation for just one height feature[3] since, on the surface, the trigger and target do not share all height features.

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[2] Schane (1990, Clements (1991), and Clements and Hume (1994) use the term "Aperture" to characterize this constituent in recognition of the fact that tongue height is not directly correlated to phonemic height (Ladefoged. 1971, Lindau. 1975). Here, the familiar term Height is used in reference to phonemic height.

[3] The "all or one" option described here follows Clements (1985) and others who argue that phonology operates on only *single* elements — a node or feature. For a different view, see Halle. 1995, Padget. 1994.

In the incremental constriction model, vowel height is characterized exclusively by the feature [closed] so that a partial height assimilation constitutes an assimilation for one occurrence of this feature. As [closed] is monovalent and corresponds to increased vowel height, the incremental constriction model predicts that all partial height harmonies necessarily involve raising. Because the feature [closed] is incremental with occurrences of [closed] distinguishing steps along the vowel height continuum, the incremental constriction model predicts that all partial height assimilations involve a single-step change.

(4) Prediction of the Incremental Constriction Model.
All cases of partial height harmony involve one-step raising.

The incremental constriction model holds that all height distinctins are characterized by [closed], but recognizes that some language require the features [ATR] or [tense]. It is argued here that [ATR] and [tense] not be used as an ersatz device to characterize a langauge with more than three heights (the maximum contrasted with [high] and [low]). Instead, [ATR] is reserved for languages that exhibit true cross-height harmony, e.g., Akan (Stewart 1969, Lindau 1975) and that [tense] is used only for languages such as German.

2.3 Llogoori

Llogoori (Leung 1986) is Bantu (E41) language spoken in Kenya, and is a member of the Luhya group. Llogoori contrasts the vowels in (5.a),[4] and requires three occurrences of [closed] to characterize its inventory. The Llogoori vowels are characterized in the incremental constriction model as in (5.b).

(5) Llogoori vowels.

a.			b.				
i	u		i	u	ɪ	ʊ	ɛ ɔ	a
ɪ	ʊ	[closed]	•		•		•	
ɛ	ɔ	[closed]	•		•			
a		[closed]	•					

The examples of Llogoori verbs in (6) consist of a pronominal prefix, a verb stem, and a final vowel marking the subjunctive mood. The final vowel for many tenses is *a*, but in the examples from the subjunctive below, the final vowel surfaces as *ɛ* or *ɪ*.

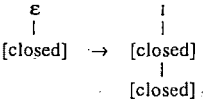
(6) Llogoori partial height harmony.

a.		b.	
kɛ-vɛg-ɛ	'shave it'	kɪ-guut-ɪ	'defeat it'
kɛ-rɛɛt-ɛ	'bring it'	kɪ-vis-ɪ	'hide it'
kɛ-ŋoor-ɛ	'obtain it'	kɪ-guriz-ɪ	'sell it'
kɪ-karag-ɛ	'cut it'	kɪ-vis-ɪ	'hide it'
kɪ-saamb-ɛ	'burn it'	kɪ-duɣ-ɪr-ɪ	'hit for it'
		kɪ-kɪn-ɪr-ɪ	'play for it'
		kɪ-rʊm-ɪ	'bite it'

The final vowel is always a front vowel in the subjunctive, and surfaces as *ɛ* when preceded by a vowel of the same or lower height (6.a). The final vowel raises to *ɪ* when preceded by a higher vowel (6.b).

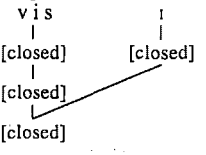
[4] Llogoori, like many Bantu languages (e.g., Kikuyu, Kimatuumbi) contrasts three heights where the upper "mid" vowels are pronounced as *ɪ ʊ* and the low mid vowels are *ɛ ɔ*. Leung (1986) uses the symbols *e o* for the lower mid vowels while *ɛ ɔ* are used here for consistency with the vowels represented by these symbols.

(7) Effect of partial height harmony in Llogoori.



Since Llogoori raising (6) is assimilatory, the surface form of *visɪ* should have some structure shared between the triggering *i* and the harmonizing *ɪ*. The assimilation in (6) is not a complete height harmony, so the shared element cannot be the Height node. Instead, a single instance of [closed] should be multiply linked between the trigger and target such that the harmonizing vowel is specified for one more occurrence of [closed] in the output than in the input.

(8) Spreading one instance of [closed].



McCarthy and Prince (1995:264-5) propose a family of constraints that require feature specifications to be identical between corresponding input and output segments. Identity constraints are feature specific, as posited by McCarthy and Prince, so that for every feature there is an identity constraint that requires that correspondent segments be featurally identical to one another. The identity constraint relevant to the representation in (8) is that requiring identity between input and output correspondents with respect to the feature [closed]. IDENT[cl] is defined in (9).

(9) Identity of [closed].

IDENT[cl] = an output segment must be specified for an identical number of occurrences of [closed] as its input correspondent.

IDENT[cl] is violated whenever corresponding segments are specified for a distinct number of occurrences of [closed]. Thus, IDENT[cl] prohibits the insertion, deletion, spreading, and delinking of [closed]. Consider the form *vis-ɪ* 'hide it,' here, the final vowel of the input is spcified for just one occurrence of [closed]. In its output form, depicted in (8), the final vowel is specified for two occurrences of [closed], thus incurring a violation of IDENT[cl].

Since multiple linkings in general are dispreferred by IDENT[CL], a higher ranked constraint must prefer the specific structure in (8) in order to allow this form to be optimal. This constraint is from the alignment family, specifically ALIGN[closed] as defined in (10). (See §2.4 for discussion of formulation of alignment constraints that make reference to [closed].)

(10) ALIGN([closed], R, root, R) — Llogoori.

ALIGN[cl] = if a vowel is specified for [closed], then the right edge of an occurrence of [closed] must be aligned to the right edge of the stem.

ALIGN[cl] is satisfied by candidates, produced by GEN, where a single occurrence of [closed] is shared between the root and the suffix. In Tableau 1, ALIGN[cl] is satisfied by the first candidate, (a), but is violated in (b) where no sharing takes place. Candidate (a) is preferred, in spite of violating IDENT[cl], establishing the relative ranking of these

constraints in Llogoori. In fact, the ranking ALIGN[cl] » IDENT[cl], is found in all of the languages exhibiting partial height harmony discussed in this paper.

Tableau 1

vis-ɛ → vis-ɪ	ALIGN[cl]	IDENT[cl]
a. ☞ vis ɪ / [closed] [closed] / [closed] / [closed]		*
b. vis ɛ / [closed] [closed] / [closed] / [closed]	*!	
c. vis i / [closed] [closed] / [closed] / [closed]		**!

Candidate (c) violates IDENT[cl] twice since it satisfies ALIGN[cl] by multiply linking a non-terminal occurrence of [closed], thereby sharing that occurrence of [closed] and its dependent. In this way, the final vowel is specified for two more occurrences of [closed] in the output than is its input correspondent. Multiple linking of non-terminal [closed] is always dispreferred since ALIGN[cl] can be satisfied by aligning a terminal occurrence of [closed].

GEN only produces candidates that obey universal, inviolable well-formedness conditions, among which is a prohibition that rules out structures in which a higher vowel assimilates to a lower vowel for the feature [closed]. This prohibition falls out from well-established notions of dominance and precedence, declaring ill-formed all tree structures in which two elements are simultaneously in both a precedence relation and a dominance relation.

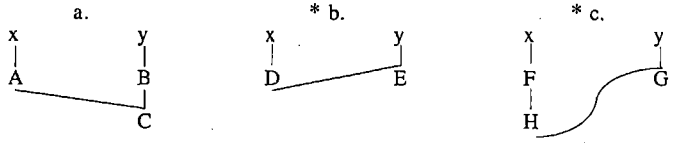
Two standard assumptions in non-linear phonology are that elements on a single tier are ordered, i.e., in a precedence relation (Sagey 1990, Kornai 1995:7), and that elements connected by an association line are in a dominance relation. Following Partee et. al. (1990:442), these relations are understood to be exclusive such that no two elements may be in both relations.

(11) Dominance/Precedence prohibition.

> If two elements are in the dominance relation, then those elements are not in the precedence relation. If two elements are in the precedence relation, then they are not in the dominance relation.

In (12.a), *A* is in a precedence relation with *B*, and *A* is in a dominance relation with *C*. This structure is permitted by (11). The structure in (12.b) violates (11) because *D* precedes *E* and *D* dominates *E*. Likewise in (12.c), because *F* precedes *G*, and *F* dominates *H*. Due to the new (dashed) association line, *H* also dominates *G*, so that (via transitivity) *F* dominates *G*. Thus, *F* both dominates and precedes *G*.

(12)



If the alphabetic nodes in (12) are replaced by occurrences of [closed], then the only permissible sharing of [closed] is one in which a higher vowel (i.e., a vowel specified for relatively more occurrences of [closed]) shares an occurrence of this feature with a lower vowel. Vowels of the same height cannot share an occurrence of [closed] so that one vowel surfaces higher than its original height, nor can a lower vowel share one of its occurrences of [closed] with a higher vowel so that the latter may surface even higher. This prohibition is understood to be universal and inviolable such that no candidate produced by GEN violates (11).

For this reason, Llogoori roots with the vowels *ɛ ɔ a* cannot share a specification of [closed] with a following affix containing *ɛ* because such candidates would be in violation of the universal prohibition, and therefore never generated.

Another constraint that plays a role in Llogoori is defined in (13). This constraint disfavors vowels that simultaneously are non-low and central. The central vowel *a* does not violate HEIGHTPL since it is low, but *ə i* do violate HEIGHTPL since these vowels are non-low and lack a peripheral place specification.

(13) Height→Place.

HEIGHTPL = if a vowel is specified for an occurrence of [closed], it must also be specified for a place feature so that it is either a front or back vowel.

In Llogoori, HEIGHTPL is ranked higher than ALIGN[cl] as illustrated in Tableau 2. The relative high ranking of HEIGHTPL ensures that *a* does not raise in Llogoori.

Tableau 2

vis-a → vis-a	HEIGHTPL	ALIGN[cl]
a. vis a ☞ [closed] [closed] [closed]		*
b. vis ə [closed] [closed] [closed]	*!	

HEIGHTPL could be satisfied by inserting a place feature on the non-low central vowel. This option is less attractive than violating ALIGN[cl] due to the more highly ranked identity constraints in (14) and (15). A place feature inserted to satisfy HEIGHTPL would violate the highly-ranked IDENT[cor] or IDENT[dor], and thus be ruled out.

(14) Identity of [coronal].

IDENT[cor] = an output segment must bear the same specification for [coronal] as its correspondent in the input.

(15) Identity of [dorsal].

IDENT[dor] = An output segment must bear the same specification for [dorsal] as its correspondent in the input.

The identity family of constraints requires that the feature specifications of output segments be identical to those of the corresponding input segmentents. The feature-specific constraints in (14) and (15) above (as well as IDENT[cl]) state that a segment in the output be specified for a feature if and only if its correspondent is secified for that feature in the input.

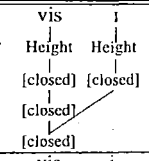
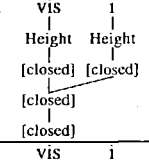
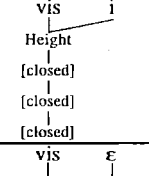
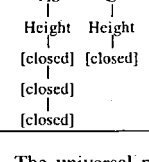
Tableau 3 demonstrates that the identity constraints in (14) and (15) as well as HEIGHTPL are ranked above ALIGN[cl], but the relative ranking among IDENT[dor], IDENT[cor], and HEIGHTPL is not crucial. The best candidate is one that violates ALIGN[cl] but satisfies the identity constraints and HEIGHTPL.

Tableau 3

vis-a → vis-a	IDENT[dor]	IDENT[cor]	HEIGHTPL	ALIGN[cl]
a. ☞ vis a [closed] [closed] [closed]				*
b. vis ɔ [closed] [closed] [closed]			*!	
c. vis ɛ [closed] [closed] [closed] [cor]		*!		
d. vis ɔ [closed] [closed] [closed] [dor]	*!			

The identity constraint in (9) restricts sharing to a single occurrence of [closed]. Multiply linking the Height node effects complete harmony, in which the entire set of height features is shared. Such a structure, candidate (c) in Tableau 4, incurs two violations of IDENT[cl]. As discussed earlier, multiply linking a non-terminal occurrence of [closed] is also ruled-out by IDENT[cl] (b).

Tableau 4

vis-ɛ → vis-ɪ	ALIGN[cl]	IDENT[cl]
a. ☞ 		*
b. 		**!
c. 		**!
d. 	*!	

The universal prohibition against lower vowels raising higher vowels (11) and the highly HEIGHTPL constraint allow only the suffix ɛ to undergo raising,[5] and only when preceded by a higher vowel. Thus, the optimal candidate generated from an input of the form *kɪ-vis-ɛ* is one in which the suffix is raised, as in *kɪ-vis-ɪ* 'hide it.'

Llogoori raising (6) constitutes a partial height harmony since ɛ does not raise to the same height as the high vowel trigger in *kɪvisɪ* 'hide it.' Examples such as *kɪrʊmɪ* 'bite it' indicate that the suffix assimilates in height to a preceding high vowel, but does not assimilate to the place of that vowel.

2.4 Alignment Constraints and the feature [closed]

Assimilation in optimality theory is most often described in terms of alignment, a constraint that favors linked structures, or sharing (Pulleyblank 1993, Kirchner 1993, among others but see Cole and Kisseberth 1994). The linked structures that result from assimilation provide a structural account for phenomena like gemminate integrity and inalterability (Schein and Steriade 1986, Hayes 1986), and restrict the set of possible assimilations to those in which the trigger and surface form of the target share some property. In the absence of evidence to abandon this view, it is adopted here.

As mentioned above, partial height harmony and complete height harmony differ both in effect and the manner in which each is expressed. In complete height harmony, both the trigger and the target surface with identical height, formalized as sharing a single Height node. In partial height harmony, the target moves toward the height of the trigger, but does

[5] The final vowel in Llogoori has only two qualities underlyingly, *a* and ɛ.

not attain that height so that the two vowels surface with distinct heights. Thus, a vowel that partially assimilates in height surfaces with a height intermediate to its original height and that of the trigger.

Assimilation is formalized as spreading in derivational non-linear phonology (Goldsmith 1979, Hayes 1986 inter alia). In non-derivational constraint-based approaches, assimilation is expressed as sharing of some element, i.e., the multiple linking of a single element to two or more prosodic elements (e.g., Pulleyblank 1993, but see Cole and Kisseberth 1994). It is assumed here that assimilation is formally represented as the sharing of an element between a trigger and a target whereby an element is multiply linked to the trigger and target. In optimality theory, this multiple linking dispreferred by IDENT, defined in (9), and violated only to satisfy a more highly ranked constraint.

(16) Assimilation in non-derivational phonology.

Assimilation for an element, *F*, is expressed as the multiple linking of *F*.

An alignment constraint that refers to a feature is satisfied when that feature is "aligned" to both edges of a domain.[6] As this paper is concerned only with partial height harmony, all assimilations discussed here are expressed as an alignment of [closed]. To account for the languages discussed here, constraints referring to the alignment of [closed] vary, from language to language, with respect to a limited number of parameters. In this section, each of these parameters is explained.

(17) Alignment and directionality.

ALIGN ([closed], L/R) = candidates are evaluated for their alignment of some occurrence of [closed] to the left or right edge of the word.

Constraints may evaluate the alignment of [closed] with respect to directionality. In many cases, the direction of alignment is predictable, e.g., in Romance metaphony, since only suffixes trigger raising, alignment is evaluated to the left in this case. In other languages, however, the direction in which ALIGN[closed] is evaluated plays a more critical role. In languages such as Setswana, in which alignment is evaluated for all occurrences of [closed] whether affiliated with stem or affix and for vowels of all heights, directionality plays a greater role. In Setswana, [closed] is aligned leftward from any vowel to another (so long as the vowel on the right is higher than that on the right) so that the constraint takes the form of ALIGN[closed](L).

(18) Alignment and morphological affiliation.

ALIGN ([closed], Stem/Affix) = alignment is evaluated only for occurrences of [closed] affiliated with vowels in a stem or a particular affix.

Constraints may refer to whether an occurrence of [closed] is affiliated with a vowel in some particular morphological domain, e.g., stem, prefix, or suffix. For example, in Romance metaphony, only high vowels in suffixes trigger raising. In Setswana, however, any following vowel may trigger raising. Thus, the alignment constraint active in languages that exhibit metaphony take the form of ALIGN([closed]$_{max}$, Suffix), where *max* allows this constraint to be violated only with respect to high vowels, and *Suffix* allows this constraint to be violated only with respect to occurrences of [closed] affiliated with suffix vowels.

[6] For the languages discussed here, the relevant domain is defined as having two edges, one of which is the segment with which the feature [closed] is affiliated, and the other is the begining or end of the word.

(19) Alignment and height of the trigger.

ALIGN ($[\textbf{closed}]_{max}$) = alignment evaluated only for occurrences of [closed] affiliated with high vowels, i.e., the vowels specified for the maximum number of occurrences of [closed] active in the language.

Constraints (and thus languages) refer only to $[\text{closed}]_{\text{max}}$ or to a general occurrence of [closed]. For example, in Nzebi and in Basque, only high vowels, i.e., vowels specified for the maximum number of occurrences of [closed] active in that language (denoted as $[\text{closed}]_{\text{max}}$), trigger raising while in Llogoori and in Setswana, raising is triggered by any higher vowel. Of course only higher vowels are permitted to trigger raising in lower vowels due to the dominance/precedence constraint (11). Thus, in Nzebi, the alignment constraint will take the form of ALIGN[closed] (*max*) and is violated only for the misalignment of [closed] affiliated with a high vowel while in Setswana, the alignment constraint makes no mention of *max* and is violated by any misalignment of [closed].

For consistency with the recieved form of alignment constraints, the alignment constraints used in this paper will make reference to the left or right edge of the feature [closed], though the particular edge is always predictable from the direction of the sharing.

(20) Template for constraints referring to the alignment of [closed].

$$\text{Align[closed]}\left(\begin{matrix}\emptyset \\ \text{max}\end{matrix}, \begin{matrix}\text{prefix} \\ \text{root} \\ \text{suffix}\end{matrix}, \begin{matrix}\text{L} \\ \text{R}\end{matrix}\right)$$

The parameters discussed above allow for the logical possibilities in (20); a constraint may refer to an occurrence of [closed] that is affiliated with a high vowel or any vowel (ø, or *max*), a vowel in the prefix, root, or suffix, and may require that feature to be aligned leftward or rightward. Each of these possibilities is attested in the languages discussed in this paper, with one exception. No language has been uncovered in which a prefix to vowel triggers partial height harmony.

3 Partial Height Harmony

As partial height harmony is expressed as an assimilation for a single height feature, the incremental constriction model predicts that all partial height harmonies involve one-step raising (cf. §2.2). In each of the languages discussed below, and as was true of Llogoori, partial height assimilation is expressed as the sharing of a single occurrence of [closed] to satisfy a form of the constraint ALIGN[closed]. Each of these languages, as was true for Llogoori, bears our the predictions of the incremental constriction model (4).

3.1 Lena Spanish

The Lena dialect of Spanish (Hualde 1989a, 1989b, Kaze 1989, Dyck 1995, Martínez-Gil 1996) is spoken in Austurias, Spain. Lena Spanish contrasts three heights among the vowels *i e a o u*. In this dialect, *a* is the unique low vowel, and is specified for no occurrences of [closed]. The mid vowels *e o* are specified for one occurrence of [closed] and the high vowels *i u* are specified for two occurrences of [closed].

(21) Vowels in the Lena dialect of Spanish.

	i u	e o	a
[closed]	•	•	
[closed]	•		

Like many dialects in the Romance family, Lena exhibits metaphony, i.e., vowel alternations triggered by the suffixation of a high vowel. Metaphony in Lena affects all stressed vowels, raising them one step before a high vowel suffix as in (22). The root *gat*, for example, surfaces with a low vowel before a non-high suffix (cf. *gata* 'cat (fem. sg.)') but the root vowel raises to *e* when followed by a high vowel, *getu* 'cat (mas. sg.).'

(22) Incremental raising in Lena Spanish.

fem. sg.	mas. sg.	gloss
gát-a	gét-u	'cat'
sánt-a	sént-u	'saint'
nén-a	nín-u	'child'
bwén-a	bwín-u	'good'
kóš-a	kúš-u	'cripple'
bón-a	bún-u	'good'

These examples illustrate that all non-high vowels raise one step in metaphony so that *a* surfaces as *e*, *e* surfaces as *i*, and *o* surfaces as *u*. In the incremental constriction model, these changes involve increasing the number of [closed] specifications of the root vowel by one in assimilation to a following high vowel. Metaphony is a partial height assimilation since *a* does not surfaces as a high vowel before the high vowel *u*.

(23)

H-EVAL prefers candidates that exhibit metaphony effects, i.e., the sharing of an occurrence of [closed] between a suffixal high vowel and a root vowel, since these candidates satisfy the constraint ALIGN[cl].

(24) ALIGN([closed]$_{max}$, L, suffix, L)— Lena.

ALIGN[cl] = if a suffix vowel is specified for [closed]$_{max}$, then the left edge of some occurrence of [closed] must be aligned to with the stressed vowel to its left.

This constraint favors candidates in which a high vowel suffix shares an occurrence of [closed] with the preceding root vowel. Candidate (a) in Tableau 5 violates IDEN[cl], but is optimal anyway because it satisfies ALIGN[cl]. Candidate (b) fails because it violates the highly ranked ALIGN[cl].

Tableau 5

nen-u → ninu	ALIGN[cl]	IDEN[cl]
a. ☞ nen u / [cl] [cl] / [cl]		*
b. nen u / [cl] [cl] / [cl]	*!	

The MAX family of constraints 'maximizes inputs,' or prohibits deletion by requiring all underlying segments be present on the surface. McCarthy and Prince (1995) define MAX in terms of segments. Following Lombardi (1995), it is assumed here that MAX can be

extended to refer to specific features. In this way, the constraint defined in (25) rules against candidates in which the feature [closed] is deleted.

(25) Maximize [closed].

MAX[cl] = an occurrence of [closed] in the input must have a correspondent in the output.

MAX[cl] is violated by structures such as (c) in Tableau 6 where ALIGN[cl] is vacuously satisfied by deleting an occurrence of [closed] from the suffix vowel. Note that candidates (a) and (c) are equivalent with respect to IDEN[cl], each incurring a single violation, and that MAX[cl] must be active in Lena to rule out (c).

Tableau 6

bón-u → bún-u	MAX[cl]	ALIGN[cl]	IDENT[cl]
a. ☞ bún u [cl] [cl] [cl]			*
b. bón u [cl] [cl] [cl]		*!	
c. bón o [cl] [cl]	*!		*

In Lena, STICPL is active, but ranked above IDENT[cor] so that *a* may undergo raising, but must surface with the default peripheral place, [coronal].[7] IDENT[dor] is ranked above IDENT[cor] since candidate (d) is not optimal in Tableau 7. In this way, *a* raises and fronts to satisfy ALIGN[closed] without violating HEIGHTPL. The relative ranking of ALIGN[closed], Ident[dor], and HEIGHTPL is not crucial.

[7] The fact that *a* fronts, i.e., the fact that [coronal] is the 'default' place for vowels, is attributed to universal markedness constraints (Prince and Smolensky, 1993).

Tableau 7

gatu → getu	MAX[cl]	ALIGN[cl]	HEIGHTPL	IDENT[dor]	IDENT[cor]	IDENT[cl]
a. get u ☞ [cl] [cor] [cl] [dor]					*	*
b. gat u [cl] [cl] [dor]		*!				
c. gət u [cl] [cl] [dor]			*!			*
d. got u [cl] [cl] [dor]				*!		*
e. gat o [cl] [dor]	*!					*
f. gæt u [cl] [cor] [cl] [dor]		*!			*	

3.2 Servigliano Italian

The Servigliano dialect of Italian (Camilli 1929, Kaze 1989, 1991) is spoken in the Marche region of Italy. Servigliano Italian contrasts four heights among the vowels specified in (26).

(26) Vowels in the Servigliano dialect of Italian.

	i u	e o	ɛ ɔ	a
[closed]	•	•	•	
[closed]	•	•		
[closed]	•			

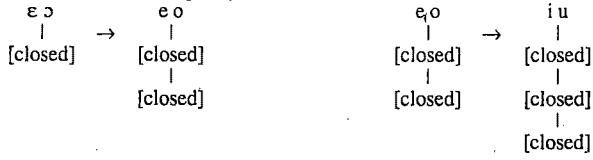
Servigliano Italian exhibits metaphony similar to that of Lena Spanish. In Servigliano, a non-low stressed vowel raises one step before a high vowel suffix. The examples in (27), from Camilli (1929), illustrate this alternation. Post tonic vowels (right of stressed) are identical to the ultima (Camilli 1929:224-5).

(27) Metaphony in Servigliano Italian.

modést-a	'modest' (fem. sing.)	modést-u	'modest' (mas. sing.)
sgwéz-a	'sinister (fem. sing.)	sgwéz-u	'sinister' (mas. sing.)
pétten-e	'comb'	péttin-i	'combs'
sprɔ́t-a	'pedantic' (fem. sing.)	sprót-u	'pedantic (mas. sing.)
mɔ́r-e	'he dies'	mór-i	'you die'
métt-o	'I put'	mítt-i	'you put'
kréd-o	'I believe'	kríd-i	'you believe'
fjór-e	'flower'	fjúr-i	'flowers'
spós-a	'wife'	spú-su	'husband'
métt-a-la	'put it (fem.)'	mítt-i-li	'put them (mas.)'
métt-o-lo	'put it (mas)'	mítt-u-lu	'put it (mas. mass)'

The examples above illustrate that *ɛ* raises to *e*, *ɔ* raises to *o*, *e* raises to *i*, and *o* raises to *u* when followed by a suffix containing a high vowel. These changes represent a partial height harmony in which non-low vowels gain a single occurrence of [closed].

(28) Effects of Servigliano metaphony.



Servigliano metaphony can be accounted for as the result of an alignment constraint, similar to that posited for Lena Spanish above, preferring candidates in which an occurrence of [closed] is multiply linked between suffixal high vowels and the stressed vowel of the root.

(29) ALIGN([closed]$_{max}$, L, suffix, L) — Servigliano.

ALIGN[cl] = if a suffix is specified for [closed]$_{max}$, then the left edge of some occurrence of [closed] must be aligned leftward to the stressed vowel.

Tableau 8

mór-i → mór-i	MAX[cl]	ALIGN[cl]	IDENT[cl]
a. ☞ mór i [cl] [cl] [cl] [cl]			*
b. mór i [cl] [cl] [cl] [cl]		*!	
c. múr i [cl] [cl] [cl] [cl]			**!
d. mór e [cl] [cl] [cl]	*!		*

As seen by examples such as bárcu 'ship (mas. sg.),' the low vowel *a* does not undergo metaphony due to the high ranking of IDENT[dor], IDENT[cor] and HEIGHTPL, so that while not multiply linking an occurrence of [closed] affiliated with a high vowel suffix to *a* incurs a violation of ALIGN[closed], a candidate with only this one violation is preferred to a candidate that violates IDENT[dor], IDENT[cor], or HEIGHTPL. The relative ranking of the identity place constraints and HEIGHTPL is not crucial.

Tableau 9

bárc-u → bárc-u	IDENT[dor]	IDENT[cor]	HEIGHTPL	ALIGN[cl]
a. ☞ bárc u [cl] [dor] [cl] [cl]				*
b. bárc u [cl] [dor] [cl] [cl]	*!		*!	*
c. bórc u [cl] [dor] [cl] [cl]			*!	
d. bérc u [cl] [dor] [cl] [cor] [cl]		*!		

3.3 Nzɛbi

Nzɛbi (Guthrie 1968) is Bantu language spoken in Gabon. Nzɛbi contrasts four vowel heights among the vowels below. There is a complementary distribution between most vowels in Nzɛbi and ə. The vowel ə does not occur as the first stem vowel (V1), occurring only as the second stem vowel (V2), while *e ɛ a ɔ o* never appear in V2. The vowel *i* appears in V2 only certain morphological conditions discussed below. The vowel *u* appears in V2 only when V1 is also *u* (Guthrie 1968).

(30) Nzɛbi vowels.

	i u	e ə o	ɛ ɔ	a
[closed]	•	•	•	
[closed]	•	•		
[closed]	•			

Guthrie (1968) documents two speech rates, *normal* and *deliberate* (slow), which affect the appearance of V2. In normal speech, V2 does not surface word finally, DELIBERATESPEECH *salə* ~ NORMALSPEECH *sal* 'work'. The examples in (31) are transcribed in deliberate speech.

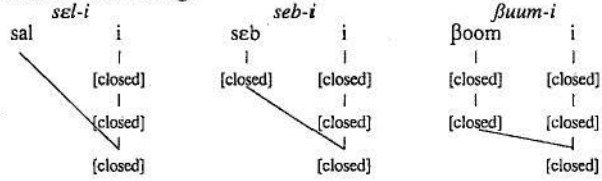
In Nzɛbi, all verbs have two forms, which Guthrie calls *simple* and *yotized*. In the simple form, V2 appears as ə, e.g., *dibəx* 'shut,' whereas the in yotized form, V2 appears as *i*, e.g. *dibix*. Examples of verbs in their simple and yotized form are provided in (31).

(31) Nzɛbi.

	simple	yotized	
e → i	betə	biti	'carry'
	bexə	bixi	'foretell'
o → u	βoomə	βuumi	'breathe'
	kolən	kulin	'go down'
ɛ → e	sɛbə	sebi	'laugh'
	βɛɛdə	beedi	'give'
ɔ → o	tɔɔdə	toodi	'arrive'
	mɔnə	moni	'see'
a → ɛ	salə	sɛli	'work'
	baadə	bɛɛdi	'be'

In the yotized forms, the high vowel in V2 triggers raising of the first stem vowel. The first vowel of the stem raises one step: *a* → *ɛ*, *ɛ ɔ* → *e o*, *e o* → *i u*. Nzɛbi raising is a partial height harmony since the first stem vowel does not always surface as the same height as the trigger *i*.

(32) The effects of Nzɛbi raising.



The multiply linked structures in (32) satisfy an alignment constraint that their non-raised counterparts violate. This constraint, ALIGN[cl] is defined below.

(33) ALIGN([closed]max, L, word, L) — Nzɛbi.

ALIGN[cl] = if a vowel is specified for $[closed]_{max}$, then the left edge of some occurrence of [closed] affiliated with that vowel must be aligned with the left edge of the word.

In Nzɛbi, as in Lena, ALIGN[cl] and HEIGHTPL are not crucially ranked with respect to each other, but both are ranked higher than the identity constraints IDENT[dor], IDENT[cor], and IDENT[CL]. This ranking, HEIGHTPL, IDENT[dor] » IDENT[cor], allows *a* to raise, but requires that it surface as a front vowel.

Tableau 10

sal-i → sɛl-i	ALIGN[cl]	HEIGHTPL	IDENT[dor]	IDENT[cor]	IDENT[cl]
a. ☞ sɛl i — [cor] [cl] — [cl] [cl]				*	*
b. sɜl i — [cl] [cl] [cl]		*!			*
c. sɛl i — [dor] [cl] — [cl] [cl]			*!		
d. sal i — [cl] [cl] [cl]	*!				

The ranking in (34) below is observed in Servigliano Italian.

(34) Constraint ranking in Nzɛbi.

ALIGN[cl], HEIGHTPL, IDENT[dor] » IDENT[cor], IDENT[cl]

For vowels that have a peripheral place feature underlyingly, the identity constraints and HEIGHTPL play no role in selecting the optimal candidate. For these forms, ALIGN[cl] determines the surface form.

Tableau 11

sɛb-i→seb-i	MAX[cl]	ALIGN[cl]	IDENT[cl]
a. ☞ seb i — [cl] [cl] — [cl] [cl]			*
b. sɛb i — [cl] [cl] [cl] [cl]		*!	
c. sɛb e — [cl] [cl] [cl]	*!		*

Tableau 12

ßoom-i → ßuum-i	MAX[cl]	ALIGN[cl]	IDENT[cl]
a. ßuum i ☞ [cl] [cl] [cl] [cl] [cl]			*
b. ßoom i [cl] [cl] [cl] [cl] [cl]		*!	
c. ßoom e [cl] [cl] [cl] [cl]	*!		*

Note that Nzɛbi is confirmation that the hypothetical language to which Contreras (1969) refers, truly exists (cf. §1). In Nzɛbi, all non-high vowels raise one step. If vowel height were characterized in terms of the features [high], [low], and [ATR], then Nzɛbi raising would defy a unified treatment, since each vowel that undergoes raising requires reference to a different feature (35, see also Clements 1991, Parkinson 1994).

(35) Nzɛbi raising with [high], [low], and [ATR].

a	→	ɛ	[+low]	→	[–low]
ɛ ɔ	→	e o	[–ATR]	→	[+ATR]
e o	→	i u	[–high]	→	[+high]

Because vowel height is characterized in terms of multiple occurrences of the same feature in the incremental constriction model, Nzɛbi raising is described with reference to only one feature, [closed].

3.4 Setswana

Setswana (Cole 1955) is a Bantu language (S21) spoken in Botswana, and is related to the other Sotho languages SeSotho and Northern Sotho. Setswana requires five occurrences of [closed] to characterize the vowels in (36). The vowels *e o* appear in underlying forms, though their distribution is extremely limited. The vowels *i u* are strictly derived from *ɪ ʊ*.

(36) Setswana vowels.

	i ụ	i u	ɪ ʊ	e o	ɛ ɔ	a
[closed]	•	•	•	•	•	
[closed]	•	•	•	•		
[closed]	•	•	•			
[closed]	•	•				
[closed]	•					

Setswana exhibits partial height harmony in which vowels of two different heights each raise one step before a higher vowel (Cole 1955, Parkinson 1994). In the examples in (37), the mid vowels *ɛ ɔ* raise to *e o* when followed by a superclosed vowel (37.a) or when followed by *ɪ ʊ* (37.b). Raised vowels are underlined for clarity.

(37) Mid vowel raising in Setswana.

rɛk-a	'buy'	mʊ-rɛ̱k-ɨ	'buyer'
lɔ-a	'bewitch'	mʊ-lɔ̱-ɨ	'witch'
bɔl-a	'rot'	sɪ-bɔ̱l-ʊ	'rotten thing'
ɛm-a	'stand'	k'ɪ-ɛ̱m-ɪ	'I am standing'
ɛp'-a	'dig'	ɛ̱p'-ʊlʊl-a	'dig out'
bɔɸ-a	'tie'	bɔ̱ɸ-ʊlʊl-a	'untie'
bɔn-a	'see'	xa-kɪ-bɔ̱n-ɪ	'I do not see'

In (37), the vowel *ɪ* appears in the negative suffix, and *ʊ* appears in the reversive suffix. The superclosed vowels *ɨ ʉ* appear as suffixes in certain noun classes. The vowels *ɪ ʊ* not only trigger the raising of *ɛ ɔ*, but also undergo raising themselves when followed by *ɨ ʉ* as seen in the examples in (38).

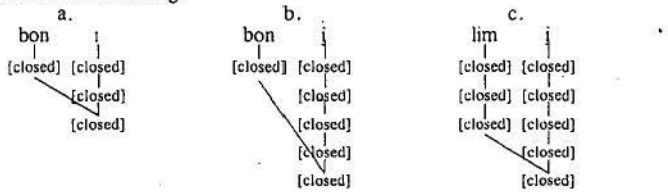
(38) High vowel raising in Setswana.

lɪm-a	'plow'	mu-lɪ̱m-ɨ	'farmer'
lɪɸ-a	'pay'	mu-lɪ̱ɸ-ɨ	'one who pays'
rʊk-a	'sew'	mu-rʊ̱k-ɨ	'tailor'
tʃʊm-a	'hunt'	mu-tʃʊ̱m-ɨ	'hunter'

The raising of the mid vowels *ɛ ɔ* and of the high vowels *ɪ ʊ* is a one-step change. Both assimilations are partial since in neither case does the target surface with the same height as the trigger. Setswana raising is described as a vowel acquiring a single occurrence of [closed] from a vowel to its right.

Due to the universal dominance/precedence prohibition (11), GEN can only produce multiply linked candidates in which the trigger is higher than the target, similar to those in (39) below. The only candidates that need to be ruled out are those in which no sharing occurs or those where the sharing is rightward rather than leftward.

(39) Effects of Setswana raising.



The alignment constraint that is active in Setswana is defined in (40). This constraint is observed throughout the root (i.e., morpheme internally) and its affixes so that no reference to the morphological affiliation of the trigger is required.

(40) ALIGN([closed], L, word, L) — Setswana.

ALIGN[cl] = if a vowel is specified for an occurrence of [closed], then some occurrence of [closed] must be aligned to the left edge of the word.

In Setswana, HEIGHTPL and IDENT[dor], IDENT[cor] are ranked above ALIGN[cl] since the low vowel *a* does not undergo raising, as seen in the form *xa-kɪ-bal-ɪ* 'I do not count.'

Tableau 13

xʊ-bal-ɪ → xʊ-bal-ɪ	IDEN[cor]	HEIGHTPL	ALIGN[cl]
a. a ɪ [cl] [cl] [cl] ☞			*
b. ə ɪ [cl] [cl] [cl]		*!	
c. e ɪ [cl] [cl] [cor] [cl]	*!		

For examples containing non-low vowels, only the constraint ALIGN[closed] is relevant.

Tableau 14

bɔn-ɪ → bɔn-ɪ	ALIGN[cl]	IDENT[cl]
a. bɔn ɪ [cl] [cl] [cl] [cl] ☞		*
b. bɔn ɪ [cl] [cl] [cl] [cl]	*!	
c. bɔn ɛ [cl] [cl]		**!

Tableau 15

xʊ-lɪm-ɟ → xu-lim-ɟ		ALIGN[cl]	IDENT[cl]
a. ☞	lim [cl] [cl] [cl] ɟ [cl] [cl] [cl] [cl] [cl]		*
b.	lɪm [cl] [cl] [cl] ɟ [cl] [cl] [cl] [cl] [cl]	*!	

Strings of vowels may also undergo raising, though as expected, low vowels and lower vowels block the process. In the examples below, a string of vowels of the same height, *ɪ ʊ* or *ɛ ɔ*, all raise when followed by a higher vowel. The examples in (41.b) illustrate that *ɪ ʊ* do nor raise when followed by a lower vowel, even if that lower vowel is raised. The example in (41.c) illustrates that [closed] may not be aligned across *a*. The vowels that do not undergo raising are boxed.

(41) Raising strings of vowels.

a.	mʊ-lɪɸ-ɟ	→	mʊ-lɪɸ-ɟ	'one who pays'
	mʊ-rʊk-ɟ	→	mʊ-rʊk-ɟ	'one who sews'
	-ɔmɛlɛl-ɪ	→	-ɔmɛlɛl-ɪ	'dry out completely (neg.)'
b.	mʊ-ɛmɛl-ɟ	→	mʊ-[ɛmɛ]l-ɟ	'one who represents'
	mʊ-bɔn-ɟ	→	mʊ-[bɔ]n-ɟ	'one who sees'
c.	mʊ-xak'ʊlʊl-ɟ	→	mʊ-[x]ak'ʊlʊl-ɟ	'one who advises'

GEN does not produce candidates in which a higher vowel assimilates to a lower for [closed], as discussed above. The highly ranked constraints of IDEN[dor], IDEN[cor], and HEIGHTPL prevent *a* from undergoing raising.

Tableau 16

mu-xak'ululi	IDEN[cor]	IDEN[dor]	HEIGHTPL	ALIGN[cl]
a. ʊ a μ μ i ☞ [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl]				* *
b. ʊ ə μ μ i [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl]			*!	*
c. ʊ e μ μ i [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cor] [cl]		*!		*

Each candidate in Tableau 16 incurs at least one violation of ALIGN[closed] since in all forms, [closed] is not aligned to the prefix vowel. The winning candidate violates ALIGN[closed] twice since neither the prefix vowel nor *a* is linked to [closed] affiliated with the *i* in the suffix.

(42) No Gapped Configurations.

NOGAP = multiple linking across an eligible anchor is prohibited.

To rule out a fourth candidate, the constraint NOGAP (42) is posited to be ranked higher than ALIGN[closed]. NOGAP (adapted from McCarthy 1995, Padgett 1995) is a violable constraint that prefers structures in which no element is skipped in a multiple linking.

Tableau 17

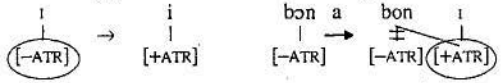
mu-xak'ululi	NOGAP	ALIGN[closed]
a. ʊ a μ μ i ☞ [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl]		**
b. ʊ a μ μ i [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl] [cl]	*!	*

While the Setswana facts may resemble a cross-height harmony of the type found in Akan (Stewart 1967, Lindau 1975), an analysis based on [ATR] is not tenable, however.

An [ATR] analysis fails because it requires a contradictory specification for the vowels *ɪ ʊ*, and must make crucial reference to the height of trigger–target combinations.

In an [ATR] analysis, the vowel *ɪ* must be specified as [–ATR] and become [+ATR] before the vowels *i u* (43.a). But, since *ɪ* also triggers raising of [–ATR] *ɛ ɔ* to [+ATR] *e o* , this vowel must also be specified at [+ATR] (43.b).

(43)



If Setswana were a cross-height harmony, then raising would be expected to apply between any [–ATR] target and [+ATR] trigger combination, so that *ʊ* raises to *u* before *e*, since [ATR] spreads independently of height (Stewart 1967). The examples in (41.b) illustrate that this is not the case in Setswana. Vowels only raise before higher vowels, independent of whether the trigger is raised or not.

3.5 Basque

Basque (Hualde 1991) is a language isolate spoken in northeastern Spain and southern France. Basque contrasts three vowels heights among the vowels in (44).

(44) Basque vowels.

	i u	e o	a
[closed]	•	•	
[closed]	•		

Basque exhibits one-step raising in the examples in (45). Here, the vowel *a* surfaces as *e* when it appears in a suffix following a high vowel. Basque raising is a partial height harmony since *a* does not assimilate to the place of a preceding vowel, nor to the complete height of that vowel, as seen in *layun-e* 'the friend,'

(45) Ondarroa

gišon-a	'the man'	layun-e	'the friend'
pelota-ka	'throwing a ball'	aɾ̃i-ke	'throwing stones'
ba-na	'one by one'	biɲ-e	'two by two'

Gernika

etše-ra	'to the house'	mendi-re	'to the mountain'
baśo-an	'in the forest'	lekù-en	'in the place'
baśo-tan	'in forests'	lekù-ten	'in forests'
neśka-tšat	'for/as a girl'	mutil-tšet	'for/as a boy'

Mid vowels in Basque, do not raise in this position. This is due to a constraint that disprefers high vowels. This constraint is not violated when *a* raises to *e*, but is violated if *e* becomes *i*, or if *o* becomes *u*.

(46) *[closed]$_{max}$.

***[closed]$_{max}$** = a vowel specified for the maximum number of occurrences of [closed] active in a language should not be parsed.

As high vowel do occur in the language, the constraint MAX is ranked higher than *[closed]MAX in Basque. This ranking effectively tolerates high vowels only if underlying. Candidate (e) below is ruled out because a vowel present in the input is absent in the output, thus violating Max even while satisfying *[closed]MAX.

Tableau 18

lavuna→lavune	MAX	*[cl]$_{max}$	ALIGN[cl]	HEIGHTPL	IDEN[cor]
a. ☞ u e / [cl] / [cl] [cor]		*			
b. u ə / [cl] / [cl]		*		*!	
c. u a / [cl] / [cl]		*	*!		
d. u ə / [cl] / [cl] [cl]		*	*!	*	*!
e. o a / [cl]	*!				

Since the low vowel *a* fronts when it undergoes raising in Basque, ALIGN[cl] ranked higher than the identity constraints and HEIGHTPL.

Tableau 19

u - e → u - e	MAX[cl]	*[cl]*max*	ALIGN[cl]
a. ☞ u e / [cl] [cl] / [cl]		*	*
b. u e / [cl] [cl] / [cl]		**!	
c. o e / [cl] [cl]	*!		

The fact that mid vowels do not raise before high vowels is attributed to the fact that MAX is ranked above *[cl]MAX. Candidate (a) in Tableau 19 is forced to violate ALIGN[cl] in order to satisfy MAX[cl] and *[cl]MAX.

3.6 Gitonga

Gitonga (Odden pc) is a Bantu language (T32) spoken in Mozambique. Three occurrences of [cl] are required to characterize vowels.

(47) Gitonga vowels.

	i u	e o	ɛ ɔ	a
[cl]	•	•	•	
[cl]	•	•		
[cl]	•			

In Gitonga, the vowels ɛ ɔ raise one step when followed by a high vowel, as seen in the examples in (48). Here, the two forms of the locative, one marked by *ni*, the other by *tunu*, each contains a high vowel. The vowels ɛ ɔ raise to *e o* when they appear before *i u*.

(48) Raising in Gitonga.

root	*gloss*	*locative$_a$*	*locative$_b$*
sɔmbɔ	'clothes'	sombo-ni	sombo-tunu
gilatɔ	'shoe'	gilato-ni	gilato-tunu
gipɛtɔ	'circle'	gipeto-ni	gipeto-tunu
ndzɛvɛ	'ear'	ndzeve-ni	ndzeve-tunu

Gitonga raising is accounted for by positing a constraint that prefers candidates in which a high vowel shares one occurrence of closed with a preceding vowel.

(49) ALIGN([cl]$_{max}$, L, word, L) — Gitonga.

ALIGN[cl] = if a vowel is specified for [cl]$_{max}$, then the left edge of some occurrence of [cl] affiliated with that vowel must be aligned with the left edge of the word.

Tableau 20

sɔmbɔni → somboni	ALIGN[cl]	IDENT[cl]
a. ɔ ɔ i ☞ [cl] [cl] [cl] [cl] [cl]		**
b. ɔ ɔ i [cl] [cl] [cl] [cl] [cl]	*!	*
c. ɔ ɔ i [cl] [cl] [cl] [cl] [cl]	*!*	

4 Contrasting Partial and Complete Height Harmonies

All the harmonies discussed so far have been partial height harmonies in which the trigger assimilates to the target in height, but does not attain that height. Partial height harmonies are distinct from complete height harmony in that the latter results in the trigger and target surfacing with vowels of identical height. An example of complete height harmony is found in Kimatuumbi (Odden 1991), where the height of suffix vowels is identical to that of the nearest (non-low) stem vowel.

(50) Kimatuumbi vowels.

	i u	ɪ ʊ	ɛ ɔ	a
[closed]	•	•	•	
[closed]	•	•		
[closed]	•			

Kimatuumbi (Odden 1991,) is a Bantu language spoken in Tanzania that contrasts four vowel heights among the vowels in (50). While all the vowels in (50) are contrastive, the height of all non-stem-initial vowels is predictable. The height of the stem-initial vowel is

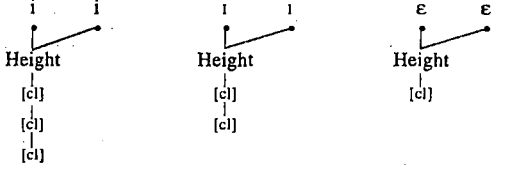
realized on all subsequent non-low vowels. All vowels following the low vowel *a* are either high, *i u*, or low, *a*. While these generalizations hold morpheme-internally, alternations found in suffixes indicates that there is an active process of harmony in the language. For example, the first vowel of the passive suffix always surfaces as a front vowel, but its height is determined by the preceding root vowel, as seen in (51).

(51) Kimatuumbi height harmony.

passive — *ilw*		causative — *iy*	
asim-ilw-a	'borow'	ut-iy-a	'to make pull'
kun-ilw-a	'dance'	yib-iy-a	'to make steal'
twɪɪk-ɪlw-a	'lift a load'	yuyʊʊt-ɪy-a	'to make whisper'
ʊʊg-ɪlw-a	'bathe'	bɪɪk-ɪy-a	'to make put'
kɛɛŋgɛɛmb-ɛlw-a	'uproot tubers'	gɔɔnj-ɛy-a	'to make sleep'
bɔɔl-ɛlw-a	'tear bark off a tree'	čɛɛŋg-ɛy-a	'to make build'
kɪŋgam-ilw-a	'follow'	kɪŋgam-iy-a	'to make follow'
		kaat-iy-a	'to make cut'

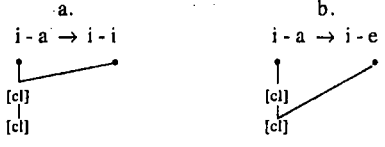
The assimilation in (51) is a complete height harmony since the assimilating vowel always surfaces as the same height as the preceding vowel. Odden (1991, see also Clements 1991, Parkinson 1994) argues that the result of complete height harmony is an assimilation for all vowel height features, expressed as sharing the Height node.

(52) Complete height harmony in Kimatuumbi.



The fact that the trigger and target surface with identical heights is reflected in the structures in (52), which share all height features. Complete height harmony is distinct from partial height harmony, then, in both its effect and its formalization. In partial height harmony, the target does not surface with the same height as the trigger, and the two vowels share only a single occurrence of [closed].

(53) Complete versus partial height harmony.



A comparison of the effects of these two types of height harmony reveals another, more important difference between them. Complete height harmony reduces the potential for contrasts. In Kimatuumbi, for example, on only possible height contrast must be realized on the stem-initial vowel, since all subsequent vowels have predictable height. In contrast, partial height harmony tends to preserve contrasts. In Nzæbi raising, height contrasts are maintained in the yotized forms for all vowels except for *e* and *o*, which neutralize with *i u*.

(54) Height harmony and height contrasts.

Kimatuumbi		Nzɛbi	
i → i	/i	i → i	/i
ɪ → i	/i	e → i	/i
ɛ → i	/i	ɛ → e	/i
		a → ɛ	/i

Recall that an assimilation for the Height node entails a MAX[cl] violation, since a shared node requires the "deletion" of the original node. On the other hand, partial height harmony does not incur a MAX[cl] violation since all underlying features are faithfully present in the output. At least with respect to height harmony, MAX acts as a constraint that favors that maintenance of contrasts.

5 Other Accounts of One-Step Raising

Kirchner (1996a, b) provides an analysis of the Nzɛbi facts within the framework of optimality theory. In his analysis, the Nzɛbi vowels are specified for the binary features [high], [low], and [ATR] as in).

(55) Nzɛbi vowels in Kirchner 1(996a, b).

	i u	e ə o	ɛ ɔ	a
high	+	–	–	–
low	–	–	–	+
ATR	+	+	–	–

Kirchner (1996a, b) analyzes Nzɛbi raising as being morphologically conditioned. Raising, in this analysis, is analyzed as satisfaction of the constraint RAISING (56).

(56) Raising.

Raising = maximize vowel height (in verbs when occurring with certain tense and aspect affixes).

To mitigate against the complete satisfaction of RAISING, Kircher (1996a) posits constraints (57) that are satisfied when an output vowel "preserves" the feature specification of the input vowel (i.e., these are functional equivalents of "identity constraints" and are replaced by PARSE in Kirchner 1996b).

(57) Preserve constraints.

PRESERVE[low] = if [low] is specified α in the input, it is specified α in the output.

PRESERVE[ATR] = if [ATR] is specified α in the input, it is specified α in the output.

PRESERVE[high] = if [high] is specified α in the input, it is specified α in the output.

Kirchner (1996) then establishes a disjunction realtion for pairs of the PRESERVE constraints, so that the disjoined constraints are satisfied as long as one of the two is satisfied. Thus (58.a) is satisfied if a vowel preserves its specification of [low] but changes its [ATR] specification, or if a vowels changes its specification for [low] but preserves its [ATR] specification.

(58) Disjoined PRESERVE constraints.

a. **PRESERVE[low]** ∨ **PRESERVE[ATR]** = the output must have an identical specification as its input correspondent for either [low] or [ATR].

b. **PRESERVE[high]** ∨ **PRESERVE[ATR]** = the output must have an identical specification as its input correspondent for either [high] or [ATR].

If these two constraints are not ranked with respect to each other, but both are ranked above RAISING as the tableaux from Kirchner (1996) demonstrate. In Tableau 21.a, the first two candidates satisfy both PRESERVE constraints, but the second candidate incurs fewer violations of RAISING, and is therefore optimal.

Tableau 21

	[low] or [ATR]	[high] or [ATR]	RAISING
a, a → a			***!
☞ a → ɛ	− → + [low]		**
a → e	*!	− → + [ATR]	*
a → i	*!	*	
b. ɛ → a	− → + [low]		**!*
ɛ → E			**!
☞ ɛ → e	− → + [ATR]	− → + [ATR]	*
ɛ → i	− → + [ATR]	*!	
c. e → a	*!	+ → − [ATR]	***
e → ɛ	+ → − [ATR]	+ → − [ATR]	**
e → e			*!
☞ e → i		− → + [high]	
i → a	*!	*	***
i → ɛ	+ → − [ATR]	*!	**
i → e		+ → − [high]	*!
☞ i → i			

Problematic to Kirchner's approach is that it does not properly rule out two-step raisings, while such raisings (outside of complete height harmony) are unattested. Two-step raisings in Tableau 21 are ruled out because of the inventory of Nzɛbi, and the constraints that Kirchner (1996a) allows to be in the disjunction relation. He states that "A pair of faithfulness constraints may be disjunctively combined iff they refer to features which define contiguous refions on some phonetic scale." Oddly, the among the features [high], [low], and [ATR], the two features most clearly defining contiguous regions on the height scale are [high] and [low], both of which refer (acoustically) to F_1 and (articulatorily) to height of tongue body, yet these two features are not disjoined. Instead, [ATR], which refers to pharyngeal volumne or tongue root advancement, is disjunctively combined with height features. That is, the disjunctions in (58) do not follow Kirchner's (1996a) guidelines.

More problematic for Kirchner's analysis is that it makes the wrong predictions for Sesotho. As shown in Tableau 22, the same ranking that Kirchner (1996) posits for Nzɛbi fails to select the correct candidate in Sesotho. Notice that the candidate selected in Tableau 22 is *two* steps higher in the output than in the input.

Tableau 22

ɛ → e		[low] or [ATR]	[high] or [ATR]	RAISING
a.	ɛ → a	− → + [low]		*!***
b.	ɛ → ɛ			*!**
c. ?	ɛ → e	− → + [ATR]	− → + [ATR]	*!*
d. ☛	ɛ → ɪ		− → + [ATR]	*
e.	ɛ → i	*!	*	

Another problem with Kirchner's (1996) analysis is that it fails to rule out lowerings. Candidate (a) is ruled out in Tableau 22 on the basis of RAISING. Intervening constraints could allow the disjoined PRESERVE constraints of Kirchner's (1996) analysis to pick candidates that lower one step.

6 Conclusion

In this paper, a new model for the description of vowel height was proposed. This new approach, the incremental constriction model, characterizes vowel height contrasts as increments along a single phonetic scale, where each height is correlated with an (additional) occurrence of [cl]. The representation of vowel height in the incremental constriction model as a continuum is consistent with the view of many phoneticians that vowel height should be characterized in terms of F1 (e.g., Lindau 1975, Tranmüller 1981). In addition, this approach allows for a straightforward account of languages like Nzɛbi, Lena Spanish, Servigliano Italian, and the Sotho languages including Setswana in which vowels of several heights raise one-step. One-step raising in these languages is elegantly described in terms of a single feature, [cl].

The discussion of partial height harmony in this paper has revealed a generalization concerning this phenomenon, which is unmentioned previously. All partial height harmonies involve one-step changes, and all such harmonies involve raising. That is, if a vowel assimilates to another for height and does not attain the height of that vowel, then the harmonizing vowel raises one step.

This generalization is missed in all other accounts of vowel height (Parkinson 1994, 1995), but falls-out naturally from the description of vowel height in the incremental constriction model. The number of languages that exhibit partial height harmony (listed in Table 1) and bear out the predictions of the incremental constriction model demonstrate that this generalization is both robust, and important for an approach to the phenomenon to capture.

There is evidence that the generalizations that hold of partial height harmonies are also true of morphological raisings as well (Bradshaw 1995, Parkinson 1996). Languages such as Gbanu (Bradshaw 1995), Basaá (Schmidt 1994), and Imonda (Seiler 1985) exhibit one-step raising in certain morphological contexts. Raising in these languages is easily handled incremental constriction model as the insertion of the feature [cl], but more problematic for other approachs. If all morphological shifts are indeed one-step raisings, then this can be viewed as additional support for the incremental constriction model.

	language	*input*		*output*	*trigger*
a.	Basque, Woleaian	a	→	e	high vowels
b.	Uyghur	a ä	→	e	higher vowels
c.	Loniu	a	→	ɛ	i
d.	Nzɛbi	a ɛ ɔ e ə o	→	ɛ e o i u	high vowels
e.	Basaá	a ɛ ɔ e o	→	e e o i u	morphological conditioning
f.	Lena Spanish	a e o	→	e i u	high vowels
g.	Imonda	a e ə o	→	ɛ i u	morphological conditioning
h.	Ejagham, Kikuria, Gitonga, Zulu	ɛ ɔ	→	e o	high vowels
i.	Gbanu	ɛ ɔ e o	→	e o i u	morphological conditioning
j.	Servigliano Italian	ɛ ɔ e o	→	e o i u	high vowels
k.	Sesotho, Tswana, Northern Sotho, Konzo, Kinande	ɛ ɔ ɪ ʊ	→	e o i u	higher vowels

Table 1 Languages exhibiting partial height harmony

The discussion of alignment constraints in this paper revealed that with respect to height harmony, such constraints vary with respect to only three parameters. The implication of this limited range of variation allows for all height harmony to be accounted for with a small number of constraints. Such economy is important in a theory such as optimality theory (Prince and Smolensky 1993) in which all constraints are posited to be universal. In addition, restricting variation among alignment constraints referring to [cl] suggests that the economy found for height harmony may be found in other segmental assimilations as well.

Finally, the differences between partial height harmony and complete height harmony was shown to include both the loss–preservation of height contrasts and a different ranking of MAX. This poses the question as to whether MAX plays the role of preserver of contrasts with respect to other phenomena as well. This, and the questions posed above, remain for future research.

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